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SOME ASPECTS OF EXPLORATION FOR MINERAL DEPOSITS

By B.P. WALPOLE,
K.A. TOWNLEY,
P.R. EVANS,
P.J. JONES,
K.R. VALE,
J. DALY,
N.G. CHAMBERLAIN,
J.H. QUILTY,
R.F. THYER,
F.J.G. NEUMANN,

Officers of the Bureau of Mineral Resources,
Canberra and Melbourne, Australia

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SOME ASPECTS OF EXPLORATION FOR MINERAL DEPOSITS

by officers of the Bureau of Mineral Resources, Australia.

SEARCH FOR MINERAL DEPOSITS IN UNDERDEVELOPED COUNTRIES[1]

1. The prime requirements for mineral search on a national scale are proper planning to make the maximum use of indigenous or acquired sources of technical manpower; the provision of basic materials and data which can be used to localize and control the more detailed and hence more expensive phases of mineral exploration; and adequate funds to equip and man the search. No detailed programme can be presented for 'underdeveloped countries' in general; each country has to be assessed separately. We can only indicate in broad terms the types of techniques likely to be of universal application.

2. Generally, any initial programme of mineral search must be predicated on simple techniques, easily learnt by semi-skilled operators and equipment - sturdy, simple to operate, and easy to maintain. Though some aids to exploration may be given by contractors, the main programme must be so designed that only small numbers of fully-trained scientists are employed. Emphasis is therefore placed on the use of prospectors and on field survey parties of which only the leader need be an experienced geologist.

3. The more important basic materials and data in which most underdeveloped countries are lacking are air-photo coverage, topographic base maps, photogeological maps and reconnaissance geological and geophysical information. All of these can be provided by contractors (the recent provision of photogeological maps to Pakistan by Canada is an outstanding example) and there are numerous firms in the world with proven competence to carry out such work without imposing a drain on local technical resources. Such surveys could also be utilized for training purposes and could provide useful experience for a cadre of scientists from the country being surveyed.

4. In Australia the provision of aerial photography and of topographic base maps is co-ordinated by the National Mapping Council made up of State and Commonwealth instrumentalities and the Army. Priorities are assigned from requests by user organizations, most of which are represented on the Council. Experience has shown that provision of air photographs and base maps before a survey commences leads to very great savings in time and effort.

5. In common with other countries, Australia is now making much use of photogeological maps for mineral search. These are prepared before the main field work in an area commences. The use of a system of transparent photo-overlays and photographic techniques, has led to a marked

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[1] Authors; B.P. Walpole and K.A. Townley, Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

increase in the rate of production of geological maps - which, in effect, are revised and refined versions of the photogeological maps. The techniques were first introduced into the country by the Institut Francais du Petrole, operating under contract to the Commonwealth Government, and have been modified to some extent to meet local requirements.

6. The photogeological maps are used for planning and carrying out reconnaissance geological surveys. The 1:250,000 scale adopted for this work is adequate for reconnaissance work and yet allows sufficient detail to delineate areas of interest for potential mineral deposits. For transport in the field full use is made of helicopters, light fixed-wing aircraft and four wheel drive vehicles specially modified for different terrains.

7. Reconnaissance geophysical surveys are adapted to the problem to be investigated. As in other countries, fixed-wing aircraft are used extensively for magnetic and scintillation surveys; and helicopters for positioning geophysicists for reconnaissance ground surveys. The geophysical methods used are standard techniques.

8. To provide reconnaissance information on distribution of metals in mineralized provinces, increasing use is being made of stream sediment sampling techniques. In the arid regions the trend is towards accumulating rock samples in volume from areas of interest and providing laboratory facilities which can cope with large numbers of elemental analyses and yet require only a small technical staff. Non-professional staff are being increasingly used for sampling operations and the laboratory problems are being met by direct-reading spectroscopy coupled with an automatic read-out system. Early surveys, however, could be adequately carried out by large sampling teams feeding samples to field laboratories, in which simple semi-quantitative tests would be undertaken by indigenous technicians under the supervision of a single geochemist.

9. The important role played by the prospector in mineral search is sometimes not given sufficient emphasis. There have been many instances of major discoveries by prospectors in Australia and other countries in recent years - some of these in areas surveyed and rejected by experienced mining companies.

10. At least one mining company in Australia has used the technique of "saturation prospecting" with conspicuous success. It trains its prospectors in general principles, without inhibiting their natural curiosity, and controls their activities only in the geographical sense, through prior photogeological mapping and geological reconnaissance. In countries where inexpensive unskilled labour is available this technique would be most useful, since success in mineral search is commonly in direct proportion to the amount of ground which is examined.

NEW APPLICATIONS OF MICROPALAEONTOLOGY IN AUSTRALIA[2]

11. Accompanying recent increases in the rate of exploration for oil in Australia, there has been a growing need for adequate palaeontological control of stratigraphy in both reconnaissance

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[2] Authors: P.R. Evans and P.J. Jones, Bureau of Mineral Resources, Geology and Geophysics, Canberra, Australia.

geological mapping and subsurface well interpretation. There are only about seventy five palaeontologists in Australia and most geological surveys are conducted by personnel with little palaeontological training. In consequence, the stratigraphic value of fossil occurrences is not always fully recognized or exploited. Under these circumstances, microfossils, samples for which may be readily and systematically collected from both field and well sections, are more likely to be useful for stratigraphic analysis. The use of Foraminifera is restricted, because many components of the Australian sedimentary basins are pre-Cretaceous in age or of freshwater origin. Most groups of microfossils have been studied at various times in Australia[3] but, to assist stratigraphers, the micropalaeontological section of the Bureau of Mineral Resources has specifically directed its attention in recent years to studies of ostracods, conodonts and palynology.

12. Research in each of these fields has assisted not only the Bureau's field surveys, but also the work of commercial oil exploration companies, particularly in the interpretation of Commonwealth-subsidized stratigraphic wells. At present the microfossils are used mainly for local correlation, while research has emphasized the need for additional information about the distribution of the macrofossils by which reference sections have been dated. However, these groups are filling gaps in our knowledge of the Australian stratigraphical column and are supplying their contributions to the search for oil.

13. Stratigraphical results have been published[4] of research into ostracods of the Fitzroy and Bonaparte Gulf Basins of Western Australia, while study is continuing of conodonts of the central Australian Amadeus and Georgina Basins and of the palynology of the eastern Australian Great Artesian Basin.

14. During the past year, studies of conodonts from Cambrian and Ordovician limestones of the Georgina and Amadeus Basins have indicated that many of these fossils are conspecific with North American and European forms, but it cannot be assumed that they have the same time-range in all three continents. Research, therefore, aims firstly to establish the conodont sequence in relation to trilobite and brachiopod faunas known to other Bureau palaeontologists, and secondly to test their zonal value.

15. So far, conodonts have been found in eight successive horizons from early Middle Cambrian to early Upper Ordovician. The sequence in neither the Georgina nor the Amadeus Basins is yet complete, but they supplement each other in the Lower Ordovician and further collecting will probably fill the gaps. Distinctive conodonts in the Upper Cambrian of the Georgina Basin[5] show that they are potentially useful for correlation of Cambrian rocks and provide a means of distinguishing the Ordovician from the Cambrian.

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[3] Crespin, Irene, Microfossils in Australian and New Guinea Stratigraphy. J. & Proc. Roy. Soc. N.S.W., 92, 133-147 (1959).
[4] Jones, P.J. Ostracod assemblages near the Upper Devonian-Lower Carboniferous boundary in the Fitzroy and Bonaparte Gulf Basins, App. 3 in Geology of the Canning Basin by J.J. Veevers and A.T. Wells, Bur. Min. Resour. Aust. Bull., 60 (1962).
[5] Jones, P.J., Discovery of Upper Cambrian conodonts in Queensland, Aust. J. Sci., 24, (3), 143 (1961).

16. The Great Artesian Basin of eastern Australia consists of Mesozoic rock unconformably blanketing strata of Precambrian to Upper Palaeozoic age. Oil exploration in the basin has continued since 1900, when gas was discovered at Roma, Queensland. Hydrocarbons occur towards the base of the Mesozoic - as at Roma - or entombed in basins under the Mesozoic blanket. Wells have to penetrate most of the Mesozoic to reach target horizons, but "classical" palaeontogical control of stratigraphy in the basin is available only in the marine Lower Cretaceous and sections of the Permian. Systematic palynological examination of the Basin commenced in 1958. By 1961 a provisional spore-distribution/time framework could be constructed from well sections scattered across the Basin as a guide to correlation. Permian and Cretaceous microplankton were also useful in the absence of other marine fossils. Almost the whole sequence from the base of the Permian to the Upper Cretaceous has been examined, although reference sections, dated by other fossil types, had to be obtained from areas outside the Basin.

17. Development of this framework is governed by the economic needs for elaboration, but it also stands as a possible basis for later research in areas where the geology at present is less certain.

RECONNAISSANCE GRAVITY SURVEYS, USING HELICOPTERS[6]

18. In the search for oil in Australia, geophysical methods of reconnaissance are necessary over most of the sedimentary basins because rock outcrops and drill holes are few and consequently normal geological mapping is difficult. Reconnaissance gravity surveys are being carried out by the Bureau of Mineral Resources, Geology and Geophysics. By using helicopters for transport, large inaccessible areas can be covered rapidly.

19. For the purposes of this paper a reconnaissance gravity survey is defined as a survey with observation stations of a sufficient density and accuracy to delineate the broad regional features in the gravity pattern and to elucidate, in so far as Bouguer anomaly can do so, the major units or provinces of a sedimentary basin. The object of this type of survey is to determine the regional structure of the sediments and to define geological provinces suitable for more intensive methods of investigation. The method is considered as a supplement rather than an alternative to aeromagnetic surveys.

20. A 7-mile by 7-mile grid of stations is an acceptable minimum station density, with additional stations where necessary. Anomaly relief of less than 5 mgal is not considered significant for this class of survey.

21. In the one operation the values of gravity, altitude and station co-ordinates are obtained with a time interval of 12 to 15 minutes between stations seven miles apart. A small commercial gravity meter and precise microbarometers are used for the gravity and elevation measurements and station locations are pricked on to airphotos.

22. Helicopters are an expensive form of transport and the operation must be planned carefully to obtain maximum efficiency. They require considerable maintenance, particularly when operating in remote and

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[6]Author: K.R. Vale, Bureau of Mineral Resources, Geology and Geophysics, Melbourne, Australia.

dusty regions and allowance must be made for unserviceability; in the Bureau's surveys to date, 25% unserviceability has been assumed for planning purposes.

23. There are a number of advantages in using two helicopters in the one operation. They work from the one base camp in adjacent areas. If one helicopter becomes unserviceable its crew is available to increase the utilization of the second aircraft; also, in the event of a forced landing the second machine is available for immediate rescue work. The Bureau has adopted the two helicopter operation for the above reasons and also because the increased helicopter utilization results in an overall reduction in the cost per gravity station.

24. Within a survey area flights are looped. Common stations are established with previous flights,and ties are made to base stations to control diurnal variations and instrument drift and to permit the distribution of errors. Stationary barometers are read at one or more base stations to establish the diurnal corrections for the traversing barometers. Radio contact is maintained constantly between the base station and the traversing aircraft.

25. In order to provide datum levels and permanent marks for re-occupation on any subsequent surveys, a network of base traverses is surveyed in advance by conventional ground methods. Generally these traverses are north-south and about 50 miles apart, with altitudes to third-order accuracy at bench marks approximately five miles apart. All the gravity data are reduced to a common gravity datum by ties to the national network.

26. There are two basic types of flight planning at present in use by the Bureau. These are termed the "Line Method" and the "Cell Method". In the Line Method, the helicopter works over the survey area in a series of parallel lines at appropriate distances, while in the Cell Method, the survey area is divided into several approximately square "cells", each of which is covered by the helicopter flying routes radiating from a central point. The cell method should provide better instrument control and consequently more accurate results than the line method; otherwise, there is not much to choose between them. The flight time involved is some few per cent in favour of the line method, but better helicopter utilization may result from the smaller flight units of the cell method.

27. Immediately on return of a helicopter to the main base camp, preliminary altitudes are computed for each new station. All station locations are transferred from the aerial photographs to the final base map. From this, latitudes are taken and preliminary Bouguer anomalies calculated. Preliminary contours are then drawn and flights for extra stations planned.

28. The results of reconnaissance gravity surveys are prepared in a series of maps at 1:250,000 scale, showing observation stations, elevations and Bouguer gravity values. The gravity values are usually contoured at 1-mgal intervals. The use of this interval is debatable because the standard deviation in Bouguer anomaly value is, under the most unfavourable conditions, about 2 mgal; the errors arise almost entirely from inaccuracy in altitude measurements. However, under favourable conditions the standard deviation may be as low as 0.5 mgal.

29. The regional gravity maps prepared from the Bureau helicopter

project are a useful contribution to oil search and are much sought after. At present approximately 150,000 square miles are being surveyed each year but a substantial increase in this rate is under consideration. The overall cost of the operation is about 12/-(Aust.) per square mile, excluding the cost of the basic ground traverses.

AEROMAGNETIC SURVEYS IN MINERAL EXPLORATION[7]

30. The aeromagnetic method is used extensively in Australia to assist in exploration for petroleum and metalliferous deposits. It is particularly applicable to regional reconnaissance surveys because of the speed of operation and ability to survey difficult terrain or water-covered areas. Direct detection of deposits of magnetic minerals such as iron ore is possible, but generally the main application of aeromagnetic surveys is to indicate areas that warrant more detailed exploration by ground geophysical methods.

31. The Bureau of Mineral Resources uses a DC.3 aircraft equipped with fluxgate magnetometer and the usual ancillary recording and navigation equipment. Flight lines are positioned either from air-photos or by Shoran; they are spaced ¼ to 1 mile apart over metalliferous regions and 1 to 5 miles apart over sedimentary basins. The reduced magnetic data are finally presented as total-intensity contour maps usually at a scale of 1:125,000 to 1:250,000.

32. In interpreting aeromagnetic data it is essential to study the data in relation to known geology. A purely qualitative approach yields information on geological boundaries, structural features and regional trends. The interpretation can be carried further by various quantitative methods which involve detailed analysis of individual anomalies and allow estimates to be made of the depth and configuration of magnetic bodies and susceptibility contrasts. From surveys over sedimentary basins, depths to the crystalline basement and hence the variations in thickness of the sedimentary rocks are determined. The following paragraphs describe three typical examples of aeromagnetic surveys in Australia.

33. A survey of the Perth Basin in Western Australia confirmed the existence of a deep trough of sediments overlying Precambrian crystalline basement. The survey showed the main structural features of the Basin including its off-shore extension; it also showed subsidiary basement ridges within the trough, and the presence of basalt flows within the sediments.

34. On the Precambrian Shield in the region of the Yilgarn and Coolgardie goldfields of Western Australia, aeromagnetic surveys have provided much new information on the regional geology in areas where soil cover makes normal geological mapping difficult. The magnetic contour patterns delineated areas of basic metamorphic rocks, which are common host rocks for gold deposition, and showed as conspicuous magnetic features the presence of banded iron formations with which, in places, iron ore deposits are associated.

35. A survey of iron deposits in rugged terrain in north-western Tasmania recorded extremely intense anomalies that indicated the location and extent of magnetite deposits. This permitted the planning

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[7] Authors: N.G. Chamberlain, and J.H. Quilty, Bureau of Mineral Resources, Geology and Geophysics, Melbourne, Australia.

of detailed ground magnetometer surveys which, together with drilling tests guided by the ground magnetic results, have proved substantial iron ore reserves in the Savage River area.

GEOPHYSICAL PROSPECTING FOR DEEP LEADS[8]

36. Alluvial deposits, known as deep leads, have yielded a considerable production of tin and gold in Australia. These deposits arise from the weathering of mineralized rocks. Minerals such as gold or cassiterite, which are resistant to the chemical processes involved in weathering and are also considerably denser than the ordinary rock-forming minerals, are concentrated by alluvial action on the beds of streams. The stream channels are gradually filled with detrital or volcanic material.

37. In the course of time, stream courses may be changed by geological processes such as tilting, so that the present drainage pattern may be very different from what it was when the valuable minerals were concentrated. In such cases, there is little or no surface indication of the position of the old channels. They must be sought by boring. However, this is an expensive process, requiring highly skilled drillers. Also, the results may be ambiguous or even misleading, owing to the presence of large unweathered boulders in the filling of the lead. There is therefore a considerable advantage to be gained if it is possible to detect the positions of the leads by geophysical methods.

38. A vertical section at right angles to the course of the lead will show the following succession: (a) filling, consisting of detrital material and possibly basalt, which may or may not be completely weathered. The filling may contain valuable minerals, either disseminated or in secondary concentrations on "false bottoms"; (b) wash, with the main concentration of valuable minerals; (c) weathered bedrock; and (d) unweathered bedrock.

39. For geophysical methods to be effective, it is necessary that there should be a clear differentiation in physical properties between the bedrock and the filling of the lead. There are two possibilities that can be exploited: the detrital and weathered material in the filling may be less dense than the unweathered bedrock, or the elastic properties of the unconsolidated filling may differ considerably from those of the unweathered bedrock.

40. The first possibility provides a basis for the application of the gravity method and the second, of the seismic method. However, if the filling of the lead consists of massive rock such as unweathered basalt, the above differentiation in physical properties will be much reduced. Massive basalt does not differ greatly in density and elastic properties from many other types of rock. Therefore, if the filling of the lead consists mainly of unweathered basalt, the application of geophysical methods is much more difficult; in many cases is impracticable.

41. Other methods, such as the resistivity method and in special cases, the magnetic method, have been applied to deep lead problems. However, they are neither so convenient to use, nor capable of giving such specific results, as the seismic and gravity methods.

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[8] Author: J. Daly, Bureau of Mineral Resources, Geology and Geophysics, Melbourne, Australia.

42. As described above, the wash containing the valuable minerals lies on the weathered surface of the bedrock. The surface at which the main discontinuity in physical properties occurs, however, is the unweathered bedrock surface, and it is this surface which can be observed by geophysical methods. So that the results of geophysical surveys may be of economic value, it is necessary that some relation should exist between the contour of unweathered bedrock and the position of the wash. This is not always the case. Two types of false indication are possible. Firstly, if the lead is wide, the wash may be concentrated, on the weathered surface, in a meandering channel which has no counterpart on the unweathered surface. In this case, geophysical methods would fail to indicate the presence of the channel. And secondly, it cannot be assumed that weathering of the bedrock is uniform. Owing to non-uniform weathering, geophysical surveys might indicate, on the unweathered surface, the presence of a channel which does not exist on the weathered surface.

43. The type of lead offering the best prospects for geophysical surveying is a relatively narrow channel with well-defined sides, and with a filling comprised of detrital or completely weathered material. The presence of massive unweathered basalt in the filling greatly reduces the possibility of successful results. If the lead is wide, this fact will be indicated by the surveys, but the results are not likely to give reliable indications of any channels carrying wash. However, if the lead is narrow and well defined, its course can be followed accurately and very little boring is necessary to test it.

44. The soundness of the above contentions has been thoroughly tested by surveys in Australia. In particular, it is found that the gravity method is a convenient means of reconnaissance surveying and, in some areas, is capable of giving more useful results than the seismic method. The magnitude of the gravity anomaly to be expected from a particular lead may be estimated roughly, as experience shows that the densities of the lead filling and weathered bedrock are generally less than that of the unweathered bedrock by about 0.6 g/c.c.

GEOPHYSICAL METHODS IN THE INVESTIGATION OF COAL DEPOSITS[9]

45. Extensive geophysical surveys have been made in Australia to investigate coal resources. The gravity method has been found particularly useful, either to investigate known coal deposits or to trace hidden coal seams. The applicability of gravity methods to mapping coal basins depends on the fact that the coal measures are generally lighter than the basement rocks on which they rest. In many places this density contrast may exceed 0.5 g/c.c.

46. The seismic method of prospecting is generally too expensive to use to any large extent in coalfield investigations. However, special problems may warrant its use; for example at Oaklands, New South Wales, seismic refraction results were used to provide data for estimating the regional gravity pattern. Also it was found that the coal measures had a characteristic velocity, which could be used to map their distribution. Seismic reflection techniques have been used in the Latrobe Valley where the structure of the coal seams can be determined. Seismic methods are likely to be used increasingly in the Sydney Basin for mapping the structure of the coal seams.

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[9] Authors: R.F. Thyer and F.J.G. Neumann, Bureau of Mineral Resources, Geology and Geophysics, Melbourne, Australia.

47. The East Gippsland Basin near the south-eastern corner of the Australian continent contains enormous reserves of Tertiary brown coal, mainly in the Latrobe Valley. The coal, which is of low grade, occurs in several seams with an aggregate thickness exceeding 1,000 ft.

48. Tertiary sediments, which are mostly unconsolidated and include coal seams, are bordered to the north and south by outcropping Jurassic rocks and Tertiary basalt (Figure I.). The coal occurs in a number of thick seams which are almost entirely concealed by sand, clay and gravel.

49. The gravity method is applicable because the Tertiary sediments are much less dense than the basement rocks on which they rest. Correlation of the gravity anomalies with known geology shows that the anomalies are caused mainly by the density contrast between the Tertiary brown coal measures and the underlying Jurassic and Palaeozoic rocks.

50. Gravity surveys have been carried out over approximately 1,500 square miles in the Latrobe Valley and adjacent areas, and the results over part of the area covered are shown on (Figure I), on which the gravity anomalies can be compared directly with the major geological structures. The most obvious correlation is that between the thickness of the Tertiary sediments and the gravity deficiency. The Tertiary sediments correspond to an area of negative Bouguer anomalies whereas the outcropping Jurassic rocks and Tertiary basalt coincide with areas of positive gravity anomalies. It will be seen that the trend of the gravity contours closely parallels the trend of the known geological features. Faults and monoclines (which probably overlie faults in the basement rocks) are clearly shown by zones of relatively steep gravity gradient.

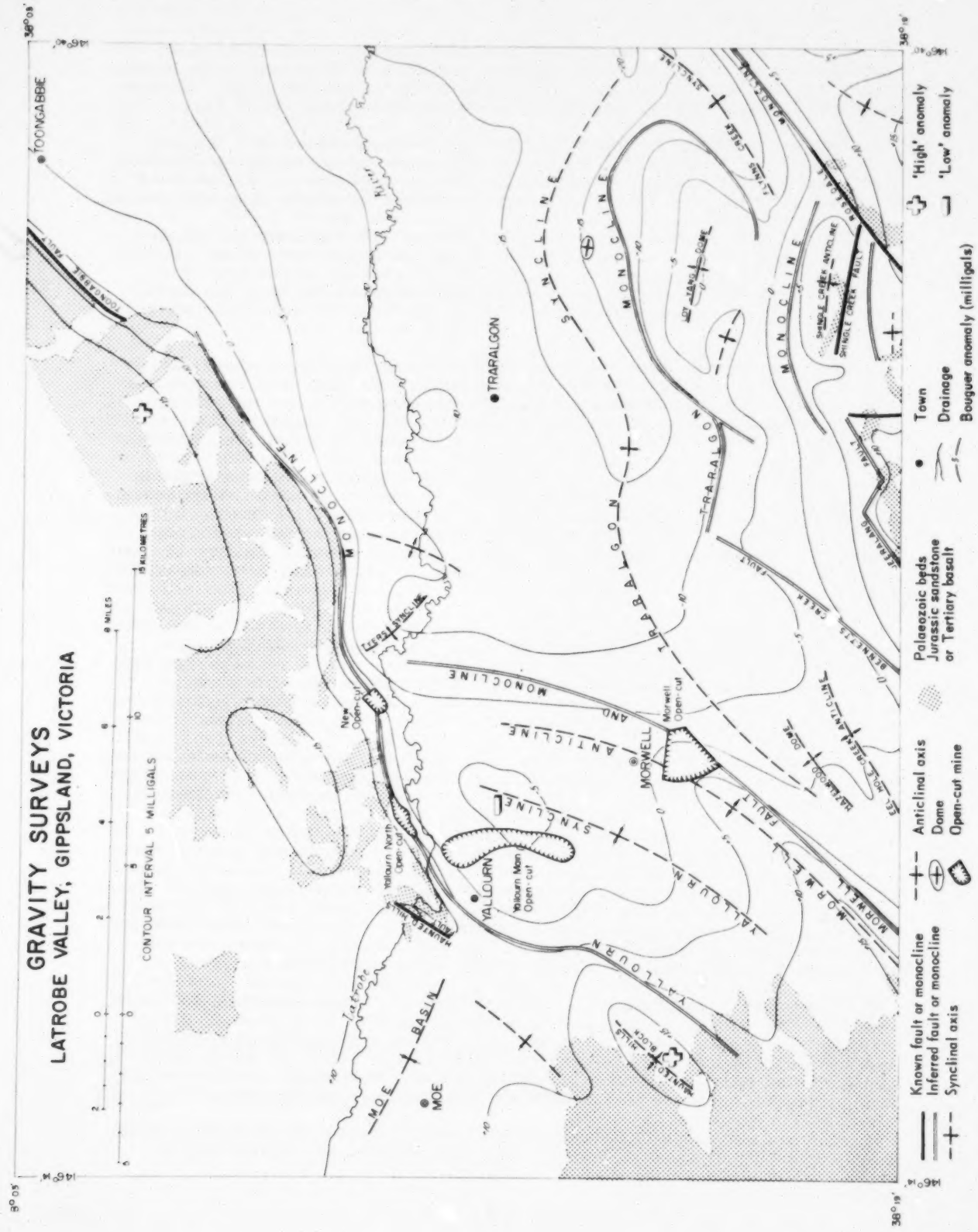
51. Of particular economic interest are the Morwell Anticline and the Loy Yang Dome, which are clearly portrayed in the gravity contours. On these structures, thick coal seams have been proved beneath shallow overburden. A major open-cut has been developed on the northern plunge of the Morwell Anticline and the Loy Yang site will no doubt also be developed when it is needed.

52. The gravity results have been of considerable value in determining the geological structure so that drilling could be carried out to best advantage. A good example of the use of the gravity data for this purpose is provided by developments along the northern edge of the valley. Hard brown coal of better quality had been mined from the Yallourn North open-cut. Coal in this seam was originally considered to be an isolated block because early exploration drilling had failed to find any extensions of it. This is perhaps not surprising when it is realized that this coal seam, although in places more than 200 ft thick, occurs mainly on a steeply dipping monocline. Bores must therefore be very accurately placed to intersect the coal, which is irregular and at places intersected by folds and many minor cross-folds.

53. After the initial gravity reconnaissance it was realized that the monocline is clearly shown in the gravity results by a zone of steep gravity gradients. Detailed gravity surveying was extended eastward, and the results revealed a comparatively narrow trend of steep gravity gradients similar to those obtained over the monoclinal feature with which the coal seam is associated in the Yallourn North open-cut.

54. The zone of steep gradients was shown to continue east and north-east for at least nine miles. It was interpreted as indicating an

extension of the monocline and, by inference the associated coal seam was expected to be present over this distance at relatively shallow depth. Drilling based on this interpretation proved that the coal seam did extend in this way and additional reserves exceeding 100 million tons have been proved.



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